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Condition-Based Maintenance: Perspectives of the Regulators, the Manufacturers and the Operators in the Power Industry

Robert E. Hall - Brookhaven National Laboratory, USA

Abstract

As systems designs become more complex and their integrated performance required for public safety as well as business financial success becomes more essential, the role of test and maintenance gains in importance. Strategically, test and maintenance consume high levels of resources, and if focused correctly, can assure the continued operation of systems within their design envelope. However, if an adaptive process is not in place, it can lead to false security and even aggravated system failure through realignment and calibration errors or early component wear out. As an example over the last 10 years the commercial nuclear power industry has been working toward an optimum Condition-Based Maintenance in place of a scheduled test and maintenance process. This effort has concentrated on developing a better understanding of system performance under unanticipated environments, as well as the subtle changes brought about by the aging phenomena, developing analytical approaches that can be used to model the nonlinear characteristics of the progress of an event or accident, and practical methods through a maintenance rule and risk-informed regulations.

This paper will discuss these independent efforts in an integrated manner. It will present the vision that all highly-engineered systems have the same basic requirements for an effective test and maintenance program. As such, we engineers, manufacturers, operators, and regulators need to move, where practical, to a unified method to collect, store, analyze and share information about system performance and condition-based maintenance. Whether the system supports a process facility such as a nuclear power plant, aircraft, marine vessel, or space craft, common areas need to be identified and leveraged. Where true industry uniquenesses exist, they should be handled as the exception, not the norm.

HUMs into the maintenance process

B. Maino – Agusta S.p.A., Italy

Abstract

Life Cycle Cost (LCC) is one of the most important issue in the helicopter total costs of ownership. The HUM systems look as the most promising tools to reduce the LCC, provided they can be exploited at their maximum extent.
This paper is an overview on the Agusta way to implement and make use of the HUM systems, with particular emphasis on the transmission vibration monitoring, the helicopter usage monitoring and the data management.

Helicopter Fatigue Life Monitoring in the 21st Century

A.A. ten Have – NLR (National Aerospace Laboratory), The Netherlands

Abstract

Traditionally, helicopter fatigue life monitoring has been the domain of structural engineers, mainly focussing on the Safe-life approach. In order to reduce inherent conservatism in the Safe Life design process of helicopter components, discussions have recently started addressing the feasibility of Flaw- or Damage-Tolerance approaches, similar to those applied in fixed wing applications.

Part of the fatigue life and load monitoring effort is always the operational implementation of suitable structural data recorders, i.e. fully autonomous on-board multi-channel data acquisition systems.

The present paper addresses some observations with respect to transitions in the design approach, i.e. from Safe Life to Damage Tolerant design, and transition in monitoring procedures, i.e. from off-line, sensor based monitoring for diagnostics purposes to on-line, intelligent-system based monitoring for prognostics purposes. Some examples using helicopters and fighter aircraft will be given.

Maintenance Malfunction Information Report

Edward F. DiCampli – Helicopter Association International, U.S.A.

Abstract

When the Federal Aviation Administration (FAA) was created from the Civil Aeronautics Board, a comprehensive set of Federal Aviation Regulations (FAR's) was developed. From the beginning, these FAR's contained service difficulty reporting requirements. The FAA recognized the importance of reliability tracking and the analysis of this historical data in the agency's overall safety program. By requiring written reports on product reliability, the FAA intended to detect potential incipient failures and negative trends. Early identification of potentially fatal failures could provide overwhelming positive benefit to the aviation industry. For this reason, the Service Difficulty Report (SDR), Mechanical Reliability Reports, Mechanical Interruption Summary Reports, and Continuing Analysis and Surveillance programs are all regulatorally mandated, and are intended to be an integral part of the FAA's overall mission to enhance safety of flight.

As the FAA recognized the importance of reliability reporting for safety, the helicopter industry recognized the necessity of reliability tracking for reasons of safety and economy. Historically, the profitability of helicopter operators has been low. This low profit margin is directly influenced by the inherently high cost of helicopter maintenance. However, maintenance costs are just as critical in the fixed-wing industry. In determining direct and life-cycle costs, all operators need access to complete and accurate reliability data. The acquisition cost of a part or component may not be as important as its reliability cost. Reliability information is a critical element of maintenance costs.

The Service Difficulty Report (SDR) should be the cornerstone of reliability tracking. Through these SDR's, the FAA should be able to provide the historical data necessary to enhance both safety of flight and industry operating costs. However, SDR reporting increases the workload on aircraft operators, thus one reason for the low percentage of operators reporting SDR information.

In the early eighties, the helicopter industry began to focus on the need for sharing of reliability data. Around this same time frame, the world-wide oil industry was undergoing an economic crisis, which drastically impacted the helicopter industry. The need for reliability tracking from an economic perspective became even more critical. Consequentially, the Helicopter Association International (HAI), under the aegis of its Maintenance Technical Committee, initiated efforts to provide a means to collect, analyze and share reliability information otherwise unavailable.

In 1984, the HAI initiated actions leading to the Maintenance Malfunction Information Report (MMIR). By 1986, with the approval of HAI's Board, including financial backing, and with the support of HAI's staff, the Maintenance Technical Committee designed a one-page, four copy, self-carboning MMIR form. This was a "universal" form accepted by manufacturers for warranty claim and by the FAA in lieu of the SDR. Initially, HAI printed and circulated 10,000 copies of this form for field trial use.

That original MMIR form is still in use today; however, the MMIR program has evolved into a comprehensive, automated, management tool. MMIR computer software, developed by HAI, is centered around the completion of the MMIR form; however, by utilizing MMIR software, the maintenance department has permanent records in a database which can be manipulated to provide specific cost and reliability information. Reports can be electronically transmitted to HAI's MMIR database.

The most recent enhancement to the MMIR system is the ability for system users to access the data entry screen, reports, and data submission modules through an Internet browser. All of the functionality of the MMIR CD-ROM software version has been ported over to an HAI-based server, enhanced, and made available at www.mmir.com. No special software is required and the operator can access the system from anywhere on the Internet.

Future enhancements include integrating the MMIR system with advanced Health and Usage Monitoring Systems (HUMS) onboard aircraft. The Usages & Condition Monitoring, Analysis and Reporting system contains an onboard processor that receives input from sensors and accomplishes onboard processing. The data are processed as required and passed to an onboard recording unit that utilizes a data transfer card. After the flight is completed, the card is carried to a ground station and the data are downloaded. Once the data are transferred to the ground station the data are treated to additional processing and used to detect faults and exceedances that require pre-flight attention.

The MMIR program has been accepted by the helicopter industry, and favorably reviewed by the FAA. The HAI is prepared to demonstrate the functional capability of the MMIR system to fulfill the needs of the civil aviation industry for collection, retrieval, and timely dissemination of data on the performance of airframes, components, and repair and replacement parts. The main thrust of this demonstration is to enhance aviation safety and to reduce operating costs.
This demonstration program has the potential to provide the aviation industry with much needed data that would otherwise be unavailable. This will enhance overall progress in aviation safety with minimal risk and minimal expense.

Life Assessment of Pipelines by Advanced In-Service Inspection

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Abstract

ENEL (Italian Electricity Company) utilizies about 240 km of pipelines to supply the fuel oil to its thermal power plants.
In order to guarantee appropriate levels of safety an reliability of the systems involved in fuel oil transportation and in accordance with current laws regarding the matter, Enel has introduced Advanced Automatic Inspections of pipelines using IPA "Intelligent Pigs Apparatus" and, specifically for Sealines, ROV (Remote Operated Vehicles) .
IPA are adopted to verify the defectology of Pipes (i.e : corrosion, delamination, cracks and so on) operating from internal side; ROV are adopted to verify the external integrity and correct spatial position of Sealines, operating underwater.

Condition Based Maintenance of such pipelines is suggested after engineering evaluations of results obtained from the above inspections in terms of:
- optimisation (and cost saving) of future frequency inspection;
- necessity, urgency and type of maintenance and/or repairing.

Condition Monitoring In Steel Industry - Disillusions and Hopes

by Prof. Dr.-ing. Hans-Klaus Wapler, German Iron and Steel Institute (VDEh), Dusseldorf, Germany

Abstract

For a long time, also in steel industry, maintenance was organized within large hierarchically structured units. These central units had a lot of disadvantages. They were inflexible and not able to contribute for TPM-strategy.

Because of that, maintenance by and by was decentralized into smaller effective groups which were bound directly to the various production lines. Parts of maintenance were outsourced completely or purchased from contractors; own personal was reduced dramatically.

It was unavoidable that, by these developments, a lot of maintenance know-how has been displaced or totally lost. There could even arise risk, that producers loose their process capability because of

endangering the **quality** level as well as plant **availability and safety**.

To prevent that, condition based maintenance has to be intensified and monitoring systems have to be developed as a tool for every days work and for economical usage.

There are two facts which oblige to install monitoring devices for assuring process capability:

Quality Aspect: In EN/ISO 9000-2 it is demanded that processes should be definitely controlled by directly influencing production, erection and maintenance procedures. By an example from the steel rolling mill sector, it will be demonstrated that vibration control does not only give information about the load capacity of the mill stands but also about chatter conditions which heavily influence product quality. The positive results of these monitoring system give hope for further similar developments.

Availability and Safety Aspect: The EU-Machinery Directive 89/392 EEC demands that machinery must be so constructed and maintained that no one is put at risk when machines are operating. Automated machinery should be fitted with a diagnostic fault-finding equipment.

By an example of controlling a lifting gear of a big steel shop crane, transporting liquid iron, it will be shown that a severe damage occurred in spite of using a vibration monitoring system. This example is very much disappointing, but it also causes new experience to learn from.

Qualitative Criticality Methodology for Offshore Plants

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Abstract not available at time of printing

The Need for and Use of a Life Monitor System on a New Generation Fighter Aircraft

Hans Ansell, Saab AB (publ.), SE-581 88 Linkoping, Sweden

Abstract

The basic concept behind new generation fighter aircraft is that each individual aircraft provides multi-mission capability, i.e. is instantly able to perform air-defence as well as air-to-surface strike or

reconnaissance, without any changes to the aircraft itself. Such capacity of a fleet of aircraft will certainly lead to a much different operational loading of individual aircraft. Some aircraft may predominately be used in e.g. strike mission training while others may be used in pure air patrol service.

An advanced fighter is equipped with a large number of control surfaces, elevons, canard foreplanes, leading edge flaps, airbrakes etc. This gives the pilot several options to perform a certain manoeuvre, which in turn will load the aircraft differently depending on which pilot who is flying the aircraft.

Another aspect on future operational loading of fighters is how the flexibility of a modern electrical flight control system can be utilised in order to gain certain tactical advantages. Such changes of the flight control laws can alter the load distribution of the airframe. For an aircraft with canard foreplanes, changes may alter the loading balance between the canards and the elevons. Changes in yaw control laws may in the same way alter the load distribution between fin and rudder. Future new armament may also change the operational loading conditions for weapon pylons and their attachment points to the structure.

The durability and damage tolerance design and assessment of a fighter airframe is based on a predicted design spectrum, which generally consists of a typical mix of different mission types. Service lives of safe life components and inspection intervals for damage tolerant structure are based on this design spectrum. It is thus desirable to design for a more severe usage according to the situations mentioned above but it can never be made completely due to weight and cost points of view.

The expected usage variability and the fact that the airframe is designed for one specific usage spectrum makes up an urgent need for procedures to monitor the actual usage of individual aircraft. The aspect of a loads monitor system affects both flight safety requirements and cost efficient maintenance procedures. There are several methods and procedures in use to handle the tracking of real service loads. There are two main principles for service loads monitoring. One is founded on direct measurements of loads using calibrated strain gauge installations while the other makes use of recorded flight parameters and a theoretical model to calculate the loads indirectly. The first method has its advantage in the direct recording of loads in pre-selected vital structure. The main disadvantage is that other structure is not monitored at all. The main advantage with the second method is that all structure covered by the loads model can be handled. The disadvantages are that the load model can be unreliable for some structure or load cases and that it does not to pick up unpredicted vibrations. A mix of the two systems is sometimes preferable. When real service loads spectra are in hand, comparisons with design spectra can be made and inspection intervals can be revised if necessary.

In the present paper, examples are given which highlights the variability of loading spectra to be expected in a multi-role fighter aircraft. An outline of a loads monitor system in use in a new fighter aircraft will also be given.

Mission Life Prediction for the Advanced Amphibious Assault Vehicle

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The United States Marine Corps, with its industry partner General Dynamics is currently in the process of designing and building the Advanced Amphibious Assault Vehicle (AAAV). This amphibious platform will move from United States Navy ships at sea to the objective beach at a water speed of 25 knots driven by a 2600 horsepower engine. Transitioning to a land vehicle, the same engine will propel the AAAV across the ground at speeds up to 45 miles per hour.

The AAAV program plan calls for building 1013 vehicles. The Total Ownership Cost (TOC) will exceed $11B. TOC includes all costs associated with the research, development, procurement, operations, logistical support and disposal of the platform.

The Department of the Navy recently launched an initiative to apply Science and Technology resources toward TOC reduction. One aspect of this program will use Condition Based Maintenance (CBM) technologies to provide a Mission Life Prediction (MLP) capability on the AAAV.

The five-year S&T program will build on investments made by the Office of Naval Research (ONR) in CBM from 1996-present. These investments have included basic and applied research in areas such as oil monitoring, smart sensors and corrosion control. In addition to program investments, the ONR CBM program has partnered with other Department of Defense entities, academia and industry in several Dual Use (DUST) programs. These programs have invested in wireless, smart sensor development and an Open Systems Architecture for CBM (OSA CBM).

Conceptually, the General Dynamics/Marine Corps team and ONR will decide where and how to insert CBM enabling technologies on the AAAV. Likely candidates are the MTU diesel engine, the Allison transmission and the pair of waterjet propulsors. Wireless sensors at the component level will "sense" vibration, temperature or whatever measurable parameter is desired by the customer. The sensor will be self-calibrating and incorporate onboard signal processing. A presently unfunded area of research would explore power scavenging (vice battery power) for these sensors. Anomalous data will be transmitted to a system level and then to a platform level monitor for data sensor fusion. The results of this data fusion will be used to predict future mission life or tell the Tactical Commander how much "fight" is left in his equipment.

Informing the Commander of the "fight" left in his combat systems is a benefit that cannot be quantified. Future battles will be won and lost based on the access to and denial of information and real-time equipment status supports Marine Corps doctrine that calls for development and use of comprehensive command and control.

There are however quantifiable benefits of Mission Life Prediction and these fall in the area of TOC reduction. TOC for a platform such as AAAV is made up of several components, the largest of which is Operating and Support (O&S). O&S for AAAV exceeds $7B and consists of maintenance, overhauls, spare parts, fuel and personnel. Not all of O&S however can be impacted by CBM, but the slice is large enough (32% of O&S or $2.3B) to make this program a worthwhile S&T investment.

CBM technologies will make an impact in the area of O&S and enable the high objectives in terms of manning and reliability demanded by the Marine Corps. These technologies will also enable a reduced maintenance infrastructure, reduced spare parts inventory and a leaner logistics concept.

A CHAOS BASED MONITORING AND DIAGNOSTICS TOOLBOX FOR INDUSTRIAL APPLICATION

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Abstract

In the last years, in the field of mechanics of vibration and diagnostics of machinery, increasingly sophisticated monitoring systems have been developed, to early detect arising anomalous operating conditions before destructive levels for the machine itself are reached.

The paper reports the description and some preliminary results of a research under development by the authors. Diagnostic modules mainly based on chaos quantifiers, make possible, by processing signals taken from the system under examination, to detect the presence of nonlinearities and therefore to pinpoint, at an earlier time than the traditional methods, the presence of an anomalous chaotic operating condition (e.g., for the rotating machinery case, hydrodynamic instability of bearings, rotor crack, rubbing between fixed and moving parts, and other typically nonlinear phenomena). While to estimate such quantifiers is quite easy for the case of computer simulated signals, larger difficulties are faced in the case of acquired signals, therefore affected by noise.

A powerful chaos indicator is the value of the fractal dimension of a signal. To that purpose, modules to compute this quantity using different methodologies proposed in literature were developed; each algorithm was preliminarily tested using computer generated signals having fully known characteristics: in such a way the values given by the modules and therefore their reliability were checked. However, noise is always problematic in a practical situation, so, in addition, a filtering software was developed for signal noise reduction based on iterative SVD decomposition: the algorithm is able to eliminate noise in a sampled signal having an experimental origin, keeping unmodified its chaotic component. It's difficult to have enough records of transducers signals time histories taken in real plants operations during instability conditions, so the code was tested using

experimental signals generated by a reduced scale model of rotor, which can be operated at will in unstable typically chaotic conditions.
The above mentioned methods for signal processing seem to be a very powerful tool to provide an useful information for study and analysis of physical systems and of rotating machinery. The original diagnostic software developed, when properly integrated to the traditional methods, can provide a better and advanced monitoring.

Structure Integrated Sensing and Related Signal Processing For Condition-Based Maintenance

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Abstract
The number of ageing engineering structures is increasing. Sectors being relevant are civil infrastructure and especially aircraft, where the phenomenon of ageing aircraft has been intensively discussed for more than a decade. The major result is that inspection has to be performed after much shorter time intervals when the aircraft approaches the end of its life. This together with an increasing number of possible locations for damage to occur leads to a non-linear increase in inspection effort required for aircraft structures.

Still these old aircraft can be flown beneficially and with the new techniques emerging in the context of smart materials and structures, where sensing and actuation devices become an integral part of the structural material, these benefits can even increase. New sensing devices of significantly lower size, lower cost, improved reliability and more powerful sensor signal processing hardware and software are allowing non-destructive testing to become an integral part of the structural material.

The general principle is that a sensor is attached to the structure which is able to monitor the respective physical parameter. The sensor signal being recorded may be amplified, filtered and in any case analysed. For the sensing device fibre optic and piezoelectric sensors have been favoured. Regarding piezoelectric sensors a so called smart layer has been recently proposed by Stanford University which can be either patched on a structure or integrated into a composite. The layer consists of two Kaptone foils, with tiny piezoelectric sensors as well as the required electric wiring integrated in between, similar to the way this is done for electronic components.

Monitoring larger structures requires a larger number of sensors and damage detection forms the primary objective of the overall problem of damage identification. A further analysis of this identification includes: severity and classification of damage, location of damage, and finally prediction of the remaining service life of the structure and possible breakdown. Altogether these objectives form four different levels of damage identification. The first three levels are mostly related to analysis, identification and modelling issues of engineering systems and signal processing. The last level of

prediction falls into the field of fatigue analysis, fracture mechanics, design assessment, reliability and statistical analysis.

In many military applications, target recognition is critical. This is the concern of image processing, the subject of much current research. In the case of distributed sensors for damage detection, the vector of data returned must be translated into a diagnosis of location and severity. In the situations where sensors of different types return information, data fusion techniques are needed which extract meaning from disparate sources.

Structure integrated sensors require a central processing unit or distributed processing network, which not only carries out data fusion from the available sensors, but decides action on the basis of the results. Many recent studies in this area are related to new developments in artificial intelligence including expert systems, fuzzy logic and pattern recognition. Artificial Neural Networks (ANNs) offer one of the most promising means of implementing data interpretation and effective pattern recognition for damage detection. More recently methods of novelty detection have been established. The methods establish a description of normality using features representing undamaged conditions and then test for abnormality or novelty. These methods provide only damage detection level, however they do not require any a priori knowledge about damage.

Most of pattern recognition methods require a significant amount of pre-processing; appropriate features must be extracted from the raw measured data. There exist a number of feature extraction procedures. Recent developments in this area include time-frequency and time-scale (wavelets) methods. Reduction of dimensionality is an other important problem in pattern recognition. This is due to the fact that computational procedures which are acceptable in low-dimensional spaces usually become impractical in high-dimensional spaces. The increased dimensionality of features is often associated with redundancy, which can be minimised using feature selection procedures. Many feature selection procedures for reduction of dimensionality have been developed. Recent applications include nonlinear transforms and mapping techniques.

Recent years have also showed considerable progress on the problem of determining the optimal number and location of sensors for damage location. This problem requires the application of different optimisation techniques. New developments in this area include Genetic Algorithms (GA) applications.

These different techniques together with the structure integrated monitoring technique will be discussed in the proposed paper and proven by different experimental results.

Health Monitoring Damage Assessment Sensors for Maintenance and Life-Cycle Management

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United States Navy spends over a billion dollars annually in maintenance and repair of aircraft. Recent estimates show that majority of these costs are associated with the effects of corrosion on structural and functional materials. An addition of this cost to the acquisition cost for a new platform usually doubles up the total ownership cost (TOC). To meet the challenge of reducing this TOC, one of the measures would be deploy "fix it only when broken" strategy. However, in order to meet military requirements on mission reliability and readiness, this strategy will only work when innovative 'smart' technologies are embedded in aircraft systems. Repair and maintenance must be performed intelligently with high degree of confidence and probability for detection of damage during service to reduce cost. Programs like Reliability Centered Maintenance (RCM) and Condition Based Maintenance (CBM) will require state-of-the-art diagnostic and prognostic tools such as sensors and expert systems, to succeed. This brief will review few intelligent sensing technologies for detection and monitoring of hidden damages due to corrosion, corrosion assisted stress cracking and fatigue. These types of failures are well recognized and documented as the leading life-limiting factors and obsolescence drivers. They are generally prevalent concerns in most aircraft problems. Combating corrosion with smarts will be the theme of this presentation; in other words, the ability to predict and control corrosion intelligently before it is too late. The newly developed advanced devices like autonomous miniature wireless corrosivity sensor, ultrasonic guided-wave detector and fluorescence lifetime imaging indicators and scanners, could change the paradigm on in-service support of existing protocols on maintenance and repairs. Insertion of such emerging technologies in defense systems within the budgetary constraints is possible and may lead to new strategies for reducing total ownership cost and obsolescence. Some of these technologies are currently under evaluation in the U.S. Navy and some members of the TTCP Group.

Application of the IEEE 1451 'Smart Transducer Interface Standard' in condition based maintenance

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IEEE 1451 is an existing standard for interfacing digital sensors and actuators to the world of micro-controllers, processors and networks. The goal of this standard is to reduce the complexities designers have traditionally faced in establishing communications between various networks and transducers. This includes the wiring, installation, calibration, error correction and addressing protocols. IEEE 1451 defines this structure so that System Integrators, Instrument Developers, Engineers or End Users can simply plug the pieces together to form a measurement system that allows transducers to interface directly to established networks and control systems. In addition, the traditional lines separating the analog transducer from the signal conditioning and data acquisition front end of a measurement system are blurring. As micro-processors, micro-controllers, ADCs and their related electronics have become smaller, more powerful and less expensive over the years, the more advantages there are to putting this increased functionality into the transducer.

Consider the case of a condition based maintenance program using vibration measurements being established for milling machines in a large factory. Traditional methods using portable data collectors have failed completely in this application due to the complexity of the cutting operation of the machines and the wear of the cutting tools over the course of it's life. Using a handheld data collector the operator would have to determine, first, if the machine was engaged in a cutting operation. A vibration signature measured while the machine was cutting product would look completely different from the vibration signature taken when the machine was in idle. Second, the operator would need to know if the cutting tool was fresh or had been used for some time, i.e worn, because once again the vibration signatures would not correlate under the two circumstances. Or worse, if the cutting tool were about to fail the vibration signature of the vibrating tool would mask the vibration of the bearings of the machine completely. In short, a measurement system needed to be developed to be able to take into account the various states of the machine and record vibration measurements at predetermined intervals.

Now, a spectrum analyzer or data logger with a dedicated personal computer could be adapted to work in this environment with various inputs from the control system telling it when to start collecting data and when not to and when to download the information to the control system. But this was considered to be too expensive to be implemented across the factory, on every line, at every machine. A distributed system needed to be developed from the ground up that could accept inputs from various sensors and notify operators of impending failures or problems.

With the IEEE 1451 standard it is foreseen that a Process Control Engineer would be able to select sensors and actuators, a Smart Transducer Interface Module and a Communications Module; connect them all together and implement the user functions wanted through the factory network. A description of IEEE 1451 and its components is examined in this paper with illustrations and examples of products available today.

Sensor Fusion in the Early Wear Regime for Condition-Based Maintenance

Authors: T.P. Sperring, E.D. Price, B.J. Roylance, A.W. Lees, M.I. Friswell, J Reintjes and P. Howard

University of Wales, Swansea (UK) and Naval Research Laboratory, Washington DC (USA)

Abstract

The essential elements of a machinery health monitoring programme comprise detection and diagnosis of the problem, and determination of what needs to be done, and when. In relation to modern military machinery operations it is essential that information obtained from appropriate sensing devices is made available without recourse to overt human expert procedures and interpretation which are patently time-consuming and highly subjective activities. Human expertise is utilised at the detection and diagnosis stages as a built-in 'hidden layer', thereby enabling these activities to be either semi- or fully automatic functions. Exploitation of human reasoning and intellectual capabilities can then be better harnessed to ensuring that modern reasoning and decision-making processes are utilised effectively in determining the subsequent maintenance activity.
To achieve these desirable goals requires that the right sensor technology is deployed. To this end, the kind of sensor technology required to perform the task of detecting and diagnosing the onset of wear-related problems in operating machinery is currently being carried out by a joint US-UK research investigation team comprising the Naval Research Laboratory located in Washington DC and the Dynamics and Condition Monitoring Research Group at the University of Wales Swansea, UK. The monitoring techniques being deployed comprise acoustic emission, vibration and wear debris analysis, respectively. Several laboratory-based test machines are being utilised to generate different wear behaviour under controlled failure conditions to establish how each technique responds to first signs of surface distress in the contact, and whether in combination they present a more complete profile of each stage of the surface deterioration.
The aim of this paper is to describe the research goals and programme, together with some preliminary results. The methods being developed for processing the raw sensor data will be discussed in relation to the kind of information that is required by maintenance engineers.

Lasernet Machinery Monitoring Technology

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Abstract

The analysis of debris present in machinery lubricating systems has the ability to provide fault-specific information in a timely manner to support diagnostics and prognosis of machinery maintenance. This capability allows the avoidance of catastrophic failures and enables improved cost-

effective asset-management philosophies, especially in the area of timely maintenance and reduction of maintenance induced failures. Essential to achieving these asset management and condition based maintenance goals, are technologies that can provide reliable early identification of fault or failure mechanisms and the degree of degradation of the machine's performance capability. These technologies must also assess the effect of the performance degradation with its impact on the machine's mission requirements, the system that it supports in a shipboard environment or the affected factory environment. The LaserNet Fines instrument delivers a technology which has significant potential in these areas. Using laser imaging techniques and advanced image processing software LaserNet Fines determines the type, severity and rate of progression of mechanical faults by measuring the size distributions, rate of production and the morphological analysis of debris particles in fluids. This instrument also has the capabilities of identifying contaminants, free water and fibers in a wide range of fluids such as mineral and synthetic lubricants and hydraulic fluids. This paper discusses these capabilities and features of the LaserNet Fines instrument along and with examples from both field and laboratory evaluations.

Adapting Data Fusion Frameworks for Condition Based Maintenance

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Abstract
The term *data fusion* was used little in the Europe until recently, except by the sensor community. In the United States the field is mature and has seen extensive application in defence and other applications. A corresponding theoretical advance has been made in methods and in frameworks for applications. The important advances in terms of condition monitoring (CM) include:

- the crystallisation of a cohesive scheme for problem definition;
- structured solution selection;
- comparisons with dissimilar application fields which have similar problem structures or solution methods;
- the blending of quantitative and qualitative methods which have produced encouraging results for CM solutions but are limited when used in isolation.

Important observations have been made at recent *Eurofusion* conferences: most fusion users find that the field is wider than they thought. Llinas described data fusion as a "cottage industry". The field is not simply about the core algorithms, but also about the way the problem is formulated and the choice of methods. The range of applications is vast. Fusion users in widely differing disciplines can shed light on structurally similar problems.
Crucially for CM, the encompassing philosophy of data fusion allows us to cross some boundaries where recent applications have faltered:

- it is possible to deal with the selection of data processing methods based on problem characteristics, e.g. data or knowledge density; the relationships are becoming clearer;

- we can merge qualitative and quantitative information, e.g. diagnostics data and expert knowledge, in a probabilistic or possibilistic framework.

There are many problems to be overcome. A number of proposed frameworks exist, and each needs work before it could be called generic. There is much to be learnt from existing methods for technique selection, even if those are heuristic and empirical. Integrated approaches will involve multi-level fusion – sensor data, novelty detection, feature classification, diagnosis and decision making.

RB199 Maintenance Recorder: an application of "on condition maintenance methods" to jet engines

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Abstract

Maintenance on-condition concepts have been applied for many years in maintenance of RB199 engines installed on Italian Air Force TORNADO aircraft. A system based on networked computers has been developed to calculate life consumption of life limited components of this engine.
Engine parameters are recorded during the aircraft mission, milked from the plane and processed by the ground station. After a data validation, the consumption of components life is calculated by ad hoc stress laws studied for each component. Results are stored in a database containing the configuration of each engine of the entire Italian Fleet. In this way the actual reduction of components life is calculated and detailed reports presented to drive maintenance activities purely based on residual life of the engine.
This approach has populated the database with up to 40,000 TORNADO missions, a unique database with a mix of training flights, Sardinia, Norway and Canada marshalling, missions in Kuwait.
This system has shown the advantages in terms of:

- Better usage of whole components life
  Introduction of full automatic calculation, instead of manual, and life algorithms based on cycles, instead of hours, has dramatically improved the estimation of the residual life. Therefore, life was increased while maintaining the same safety margin. A large amount of components, sent to the storage, could be recovered for further usage gaining up to hundreds hours of extra life.
- Engine performance trend monitoring
  Just before the take-off, pilots have to perform a defined procedure to measure engine data used to evaluate engine performance. Post flight analysis calculates the engine thrust and indicates if engine is usable on the aircraft for further missions or it must be removed for maintenance. This method pushed bench engine tests up to four times the original scheduled interval. In the next future, better algorithms shall allow moving tests to the double of the current time; investigations are ongoing to check if bench tests can be completely avoided. This approach has clearly decreased maintenance costs, saving fuel, man-hours and avoids grounding the aircraft for each spared maintenance action.

- Ad-hoc engine assembly and configuration
  The database contains information about all components of the entire Italian Air Force fleet, including the status (installed or spare) of each of them. The database supplies the clever possibility of choosing components with a similar residual life, when composing a new engine. This allows building an engine with a well-known life and avoids maintenance operations due to "untimely death" of a single component.
- Post-flight analysis and fault location
  Post flight analysis allowed air force to check for sensors problems and/or engine malfunctions to be investigated.

This program, due to its maturity and the acquired large database, has clearly demonstrated the advantages of condition maintenance approach. This paper will focus on:
- the architecture of the system;
- the effectiveness of the method used;
- the cost saving in maintenance activity;
- engine test and maintenance optimization.

trying to show the guidelines and new concepts for the next generation of maintenance stations for aircraft engines.

CONDITION – BASED MAINTENANCE OF TURBOJET ENGINES BASED ON COMPRESSOR BLADE VIBRATION MEASURING METHOD

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Abstract

The structure of a condition monitoring system to diagnose some turbojet engines has been discussed in the paper. System approach to the actual technical problem has been exemplified with fatigue crack growth within the first-stage compressor blades. Results of statistical analysis of the process of blades fatigue cracking have issued and followed with a concept of solving the problem. An optimum measuring method has been suggested as well. What has also been discussed is the method of measuring precisely the engine rotational speed and the amplitude of vibration of the first-stage compressor blades. Methods of displaying results of numerical analysis of measurements follow. The application of only one measuring line to complex, dynamic diagnosing of the engine technical condition has been presented, with: evaluation of technical condition of rotating compressor blades, analysis and identification of the flow perturbation origins, inspection of technical condition of the engine fuel and bearing systems. The operational experience gained in the course of implementing the diagnostic system into the Air Force of the Republic of Poland has also been shown.

A complex diagnostic system for the MiG-29's airframe and power plant

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Abstract

A complex diagnostic system for the MiG-29's airframe and power plant has been presented in the paper. Functional, vibroacoustic, tribological, flaw-detection-based, and thermographic subsystems as well as the diagnostic-data-processing subsystem have been distinguished. The above-mentioned subsystems can operate either as components of the whole system or autonomously, which provides high flexibility of the diagnostic system on the one hand, and reductions in both labour demand and the system's complexity on the other.

Research into diagnostic systems for airframes and power plants of aircraft have been carried out in the Air Force Institute of Technology since the early 1970s. Four diagnostic methods have been systematically developed, i.e. functional, vibroacoustic, tribological and flaw-detection-based ones. Quite recently efforts to implement thermographic methods have been initiated.

Development of diagnostic methods has been conditioned by technological level of available measuring devices and recorders. It has also been featured with considerable independence and a limited range of exchange of diagnostic information obtained with different methods. Analyses carried out in the Division for Diagnostics of Aeronautical-Engineering Products, both of literature-sourced data and operational experience, have enabled design and development of a model of a complex diagnostic system which automates the processes of examining and inferring in the fields of evaluating the health/maintenance status, fault location and health/maintenance-status forecast (in particular, of the engine and the airframe as subsystems mostly affecting reliability and safety of the aircraft and the pilot). All the efforts have given grounds for starting research works on complex diagnostic systems for the Su-22 and the MiG-29, partially financed by the Committee for Scientific Research.

The above mentioned diagnostic methods can be used independently of each other. By assumption, each of them has been designed for a specific purpose. Owing to many and various analyses it has been found that information flow among all these methods is possible; therefore, they can be integrated to form an information-transferring whole. It is also necessary to increase power of the set of methods to provide some new diagnostic quality.

The complex diagnostic system for an aircraft should include subsystems to provide the following capabilities:

- functional diagnostics,
- vibro-acoustic diagnostics,
- flaw-detection-based diagnostics,
- tribological diagnostics,
- thermographic diagnostics, and
- data-processing management and diagnostic inference.

Solving the problems of diagnosing a complex engineering object (e.g. an aircraft) requires the following items to be developed:

- a model of an object being diagnosed and its components (modules),
- models of engineering means of diagnosing,
- models of operations to process diagnostic information gained with different methods.

All these models should take account of both different levels of detail of representing the object/the

object's components (e.g. engine-rotor-blade) and variety of methods engaged.

Engineering accomplishment of a complex diagnostic system for an aircraft requires modern digital measuring systems and a microprocessor controller with "flexible" software to make it possible to develop the system as diagnostic information is collected in the course of operating of the object.

ALITALIA EXPERIENCE ON CONDITION BASED MAINTENANCE PROGRAM

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During the last thirty years and much more in the last decade, the air transport industry has progressively changed the basic mode of orienting the maintenance programs for the in service aircrafts; the research of methods for better and better controlling the effectiveness of predefined maintenance process and associated cost also was of high attention to the industry; while the flight safety has been always the main factor piloting the decision process making, the market competition and customer satisfaction were gradually increasing the sensitiveness of air carriers to a more cost oriented fleet managing philosophy; the consequential need of better addressing an individual maintenance program task in terms of what, how and when to perform was also of high contribution to improve the mode of fleet managing; in this effort, the continue monitoring of the in service industry experience has been of strategic contribution too.

The aircraft designs were of significant and progressive improvements in this period indeed; the most advanced technology devices gradually applied by the manufacturers in developing new aircrafts were drastically impacting the maintenanceability of all aircraft systems and relevant components; these were also of improved durability and reliability; meanwhile, the more and more sophisticated methods of diagnosing and preventing aircraft system malfunctions were also of accelerate developments and of more common civil aircrafts maintenance program application.

The aircraft propulsion system has been in this scenario of priority attention to both the manufacturers and the air carriers; the direct relationship between the engine total reliability and the flight safety so as the tight link between the relevant maintenance plan and the associated labour and material cost (being estimated as close to 50% of the total aircraft maintenance cost) were always of continue analysis and control to operators engineering in implementing and customizing the maintenance programs and process.

Early in 1970's most of aircraft maintenance plans were of hard times based concept; by this criteria, each aircraft main system and/or component was on wing life time limited and then removed regardless of actual condition when such a limit expired; in the most cases, the removed components were then completely disassembled in the shop for overhaul. What it was being observed from the industry experience that this maintenance mode was very ineffective in preventing premature part failures and system malfunctions; in addition, the hard time oriented maintenance program was not sensitive to engine to engine variation like in the mode of loosing performance so as it was not addressing correctly the different stress imposed to cold and hot section parts of engine; consequently it was inducing labour and material extra-cost with no direct benefits to the engine reliability.

It was clear to carrier engineering that a different approach for better managing engine fleet was necessary; starting in 1980's the availability on the market of more reliable devices (computer controlled test and analysis equipments) able to monitor the general condition of individual engine and relevant subgroups got this change feasible; at the same time, the development of engines of more expanded modularity allowed the engineering to build up shop maintenance programs of differentiate maintenance levels per individual main engine group.
These all engine fleet managing implementations are the base of the present Alitalia On Condition Engine Maintenance Program.

Oil Debris Monitoring as a technique for Engine Health Monitoring and Condition-Based Maintenance: the EJ200 experience

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The collection, followed by quantitative measurement and analysis, of the wearing particles (debris) entrapped within the scavenge oil flow is traditionally used as a method to assess the health conditions of gas turbine lubricated parts (gears, bearings). The ultimate goal is to achieve early failure detection, which means that conditions of engine distress are detected before they produce secondary damages and become evident by means of other traditional methods (vibrations, high oil temperature).

Several techniques have been devised to accomplish the task of oil debris monitoring. The consolidated method is based on magnetic devices (magnetic chip detectors) which collect a portion of the flowing particles. The major drawback is that they require a scheduled activity for direct inspection and further analysis of debris. The maintenance burden related to this activity can be very high, both for the frequency of the inspection task itself (10-20 engine running hours) and for the time to perform the actual measurement. Therefore big effort has been placed to develop devices capable to perform the operation automatically. Moving from simple warning switches (Electrical Chip Detectors), the technology is now focused on 'intelligent' systems, capable to perform quantitative measurement and provide 'early' detection of engine distress. When integrated within the Engine Monitoring System, these devices can provide an effective method to diagnose the occurrence of an engine failure.

The paper provides an overview of the emerging technologies and the existing systems for aircraft applications. Their performance is reviewed in the light of the author's direct experience with the development of the device used on the EJ200 engine, the ODMS (Oil Debris Monitoring System). The considerations related to the use of such systems are developed with care to the end-user point of view. None of these systems is currently available as an off-the-shelf product, although the experience already gained from their use is now allowing their transition from prototypes to certified products. Two of them, the ODMS on the EJ200 and the Oil Debris Monitor (ODM) on the F119, are currently in a standard engine configuration and are undergoing extensive flight testing.

Several problems are still open regarding the interpretation of the data obtained from these devices. Extensive public knowledge about the type of debris expected from specific engine failure modes is not yet available, as well as a consolidated description of debris generation profile along, failure progress. This causes difficulties in the definition of detection requirements, such as

measurement accuracy and type of output indication. Even more difficult is the verification of their fulfilment. This has determined a wide range of approaches to the validation task, mainly based on rig tests or on direct experience derived from the engine run data themselves.

In the author's perspective, the end-user expectation is the key to the achievement of the task. This requires a balanced compromise between the accuracy achievable by a detailed analysis of type and size of the debris (which ultimately leads to oil sample laboratory analysis) and the need to provide a clear go/no-go criterion for continued engine operation to the ground crew at first line (which is in its essence the basis of the electrical chip detectors operation). On the other hand, the benchmark to evaluate the benefits is represented by the performance of the magnetic chip detectors, which, in spite of measurement inaccuracy and empirical foundation, are still the adopted systems on several in-service engines. The availability of a system, which provides a reliable warning indication of incipient failure, possibly complemented by more accurate analysis methods on-ground, is considered the major goal. If such device is further integrated within the Engine Monitoring System, can provide an invaluable tool for on-condition maintenance.

Evolution of Aviation Engine Life Time Management in CIS

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Aeroengine life is one of the most important criterion of the engine competability connected with both safety and efficiency of operation.

The methodology of aeroengine life management was being changed in former USSR and CIS along with engine development. Engines of the first generation were developed for the short life time, which could be increased in the future after successful life tests and elimination of the defects appeared during tests and operation. Life tests were performed by flight tests of leaders or by engine rig tests using service cycles.

In USSR from the beginning of 70-th engines are developed for the full life. Nevertheless for a long time aeroengine maintenance was performed according to hard time between overhaul (TBO).

The allowed service life was confirmed by accelerated rig tests (using cycles equivalent in damage to a service cycle) of the engines and their main (critical) parts (parts failures of which could lead to a hazardous effect). Critical parts lives can be confirmed by engine tests and (or) by tests at laboratory facilities. However the scope of engine tests remained relatively high. Such approach ensured safety but was not economically effective.

In this connection at the beginning of the 90-th when economy in the former Soviet Union was moved to market the aeroengine life time management methods were significantly changed and it was reflected in airworthiness regulations and other regulatory documents. It was done for providing more complete utilization of the engine life capabilities, achievement of competable engine and their main part lives at the engine entry into service, reliable estimation of possible life at the early beginning of engine part development, shortening of the expensive engine life tests, harmonisation of the national and foreign requirements.

CIS regulations existing now permit to maintain aeroengines according to hard TBO as well as use Condition-Based Maintenance in the limits of hard lives of engine main parts.

The analyses of different engines has shown that Condition Based Maintenance can provide significant economical impact. But it is very important to maintain safety. So the reasons of the successful

utilization of Condition Based Maintenance in the West, impact of hardware aging on maintenance (it is typical for CIS), main causes for the engine replacement and other problems were analysed. To achieve a success the engine life management plan must include a selection of engine life management strategy with the substantiation of the possibility of ensuring safe operation at the life management selected strategy, plans for main part life management, measures for elimination of life time limitations for different engine parts and supplied components, requirements for reliability check and engine maintenance system (prognostics and health management, overhaul, etc).
Engine main part life must be confirmed by cyclic tests or (and) on the base of verified calculations using database on materials structural strength. In every case the conservative safe life conception must be used. In some cases the fracture mechanics methods must be used to confirm part life or to determine the interval of maintenance. The methods for determination admissible risk of the engine part and component failures and confirmation of their lives taking into account the failure criticality were developed.
The provision of bearing and component reliability, engine effective diagnostics, measures for prevention of engine gas path wear, engine gas temperature margin, life-saving methods of engine operation, the soft time conception for engine modules at overhaul are very important for successful Condition-Based Maintenance. The methodology and examples of these problem solutions at Condition-Based Maintenance of such engines as PS90A (Il 96 aircraft), D18T (Ruslan) et al in CIS will be discussed in the paper.

European Network on risk informed ISI (EURIS)

O J V Chapman (^)

Inspection planning for passive components is developing from prescriptive codified practices backed up by stringent regulatory requirements to a self regulating risk based environment. Prescriptive codes specify the location frequency and methods of inspection on the basis of the type and safe category of the components; that is to say, they are primarily consequence driven. However, with the increasing knowledge of plant degradation mechanisms and the improvements in the probabilistic safety assessment methods, operators are recognising the benefit in setting the inspection priorities on the basis of risk. This process has already begun in several countries, but a common understanding at EU level of risk informed inspection and its practical implementation has not been reached yet.

The main objective of the EUropean network on Risk informed ISI (EURIS) is to develop a European methodology for risk based assessment relevant for the needs of plant operators. The proposed methodology should be able to identify safety-significant categories for plant components, and to optimise the targeting of costly inspections. It will include feedback from plant operation and must indicate the specific components and the locations to be inspected, the defect to be detected, and the performance in detection and sizing to be achieved. The methodology will integrate actions or mitigation methods other than inspection, in order to manage the risk. As a consequence, risk based ISI should, by this optimisation of the ISI programme, reduce the cost and effort required whilst maintaining safety at its currently high level or above.

^ Mr. Chapman is the Chairman of EURIS

Life prediction, maintenance and failure probabilities in aircraft equipped with health and usage monitoring systems

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The development of Health and Usage Monitoring Systems (HUMS) for engineering structures has the capability to change the basis of maintenance towards a condition based one. Direct monitoring of the condition of the structure gives data on its the damage state. On its own this provides little prognosis capability, such as determination of the future damage growth rate or calculation of future service life. More accurate prognosis information can be obtained with usage monitoring data, which together with a damage law and appropriate material properties may be used to calculate the development of damage with increasing time in service. Much the most accurate prognosis will come from having both health and usage monitoring in the condition monitoring system.

For calculation of a safe life or a time for maintenance or inspection, the accuracy of the usage and the condition or health monitoring system is of great importance. This is especially true when the HUMS system is being used to claim additional time in service before inspection or replacement. Such maintenance credits are important financially, and are also of great significance in airworthiness, as the original design certification life is being extended. To maintain levels of airworthiness at the level set in the original design life, the life or maintenance interval can only be extended while the probability of failure remains less than that at the original design life under the design load assumptions. Therefore in order to calculate the extent of maintenance credit achievable with usage or health and condition monitoring, it is vital to develop a probabilistic approach.

In this paper a stress strength interference probabilistic model, for calculation of failure probability in mechanical systems will be described. In addition to fatigue, the model can represent other failure processes such as corrosion, wear and randomly occurring mechanical damage. The model has been applied to a helicopter tail rotor gear box. Probabilities of failure due to individual failure mechanisms have been calculated as a function of service life, together with system failure probabilities. The influence of usage monitoring of service loads on the calculated probability of failure due to fatigue at particular service lives has been explored using a Bayesian updating procedure. The influence of fatigue usage data on the overall probability of gearbox system failure, incorporating the other (unmonitored) failure processes has been determined.

The results show that fatigue usage monitoring can significantly reduce uncertainties in the calculated cumulative probability of failure due to fatigue. This benefits life of components dominated by this process. However, extensions in safe or maintenance life may not be possible without increases in system failure probability if the latter is dominated by failure mechanisms such as corrosion or mechanical damage. These results are discussed in the context of requirements for condition based maintenance systems for helicopters.

Risk Based Optimisation of Repair Replacement Policy for Capital Equipment

by O J V Chapman[1] & D Mauney[2]

There is an ever growing acceptance of risk, as an underlining philosophy to focus in-service inspection and maintenance. This paper attempts to develop this basic philosophy in order to provide a net present value driven optimisation of:

a) the timing and volume of inspection/maintenance carried out

b) the repair/replacement strategy for large pieces of capital equipment.

The first stage in this expansion of the basic philosophy, is to assign a quantitative probability of failure and cost to the given event. Note that this must be quantitative and not qualitative. This provides a financial measure of the risk being addressed by the specific inspection or maintenance action. Next the introduction of an efficiency associated with any remedial action i.e. inspection or maintenance action has to be introduced together with its associated cost. This converts the risk being addressed into a net financial return from the capital investment associated with the specific inspection/maintenance action. Using this framework a financial risk ranking can be derived which leads to a plot of the net financial return for the inspection. In turn this provides the optimum inspection volume for the maximum return from the capital outlay per year.

Inspection can also be thought of as concurrent with a decision on replacement. Any concerns associated with the timing of major capital outlay can be introduced as a constraint within the analysis. Here the optimisation is between continued operation with a growing inspection repair availability penalty against the improved availability but possible large single time cost and loss of availability associated with replacement.
Introducing time into the above analysis allows the time related opportunity capital investment adjustment to be included and hence a net present value can be determined as a function of time. This then provides a measure of whether or not replacement is the most cost effective option and allows a direct measure of the net present value of a given maintenance/inspection programme.

Sensitivity analyses can then provide a measure of the robustness or not of a given repair/replacement decision or inspection/maintenance policy.

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Expanding the Foundation for Prognostic Health Management in Complex Mechanical Systems

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One of the primary benefits of prognostic health management (PHM) is the ability to accurately assess whether a system can complete its intended mission. The system may be an automobile and the intended mission a family vacation, or the system may be a high-performance jet aircraft and the mission military in nature. Although the costs of unexpected system failure may differ, the general prognostic PHM system requirements are the same. The PHM system must be capable of detecting precursors to component or system failure, classifying the nature of the developing condition and accurately predicting the remaining useful life of the component or system. In addition, a comprehensive PHM system may also recommend changes in the current operating conditions to the operator that will prolong the life of the component or system or implement such life extending changes through the automatic control system. The fundamental components of a PHM system are advanced sensors and data acquisition systems, signal processing and data fusion, system models, pattern recognition and classification, automated reasoning, and interface to human users and asset management systems. The interests of system users (such as the power generation industry or the military) are driven by factors such as a need to decrease maintenance costs and improve operator safety. PHM offers potential added value to the system and eventually the ability to charge customers for actual usage and the opportunity to approach zero-downtime operation.

The Applied Research Laboratory (ARL) has assumed a role that includes expanding the knowledge base in the fundamental components of PHM systems and facilitating the cooperation of diverse members of the research, industrial supplier and user communities through the formation of consortia focused on particular prognostic health monitoring problems. Understanding the progression of faults in complex mechanical systems is one of the keys to reliable prognostic health management. ARL has constructed a number of test facilities designed to facilitate the acquisition of transitional machinery failure data. These include a mechanical diagnostics test bed, a lubrication systems test bench, a bearing test rig, an electrical generator test rig, a high-speed gearbox test rig, a torsional vibration test rig, and a battery test rig. In addition, ARL has constructed portable data acquisition systems for the collection of data in these facilities and on various fielded systems, and software testbeds for the development and evaluation of processing and data fusion algorithms. This paper describes the facilities developed at the ARL and the contributions made to the field of prognostic machinery health management.

[1] This paper describes research activities at the Applied Research Laboratory in the area of condition-based maintenance. It is a summary of previous work by the authors, co-authors and other researchers.

Assessment of Aviation Maintenance Technical Manuals

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The Federal Aviation Administration is undertaking the review of how aviation maintenance technical manuals are developed and revised, to assess the potential for erroneous material and to seek interim solutions to reduce erroneous material, short of full digitization of the information. This study will identify the processes employed to develop and update aviation maintenance technical manuals. It will further assess the degree of error that is inherent in contemporary versions of these publications, identify principal causes for such errors, and suggest practical approaches to minimize error in page-based manuals as appropriate. Finally, it will identify and summarize measurements and assessments of the effectiveness of the present system of technical manuals, including estimates of usage rates and evaluations of the mechanisms employed to make revisions.

DIAGNOSYS OF GAS TURBINE OPERATING STATE IN NATURAL GAS COMPRESSION PLANTS

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Abstract

The gas turbine maintenance can be performed mainly in the following three ways:

- "emergency" maintenance, which is carried out when the fault has already appeared;
- "scheduled" maintenance, which, at present, is widespread in industrial applications;
- "on condition" maintenance, which has been applied to aircraft engines.

The "emergency" maintenance has to be avoided because of its high costs due to the damages suffered by the engine and the loss of profits due to the standstill of the production related to the gas turbine stop. The "scheduled" maintenance is performed according to an "a priori" schedules, regardless of the effective gas turbine health state. This strategy has the advantage that "emergency" maintenance is reduced, but this often leads to replace healthy components and to gas turbine maintenance stops longer than it was effectively necessary. It seems that the most suitable solution to maximize the machine availability and reduce costs is to replace or support the regular maintenance schedules for degradation demand maintenance (on condition maintenance).

In the case of the gas turbines used in the natural gas compression plants of ENI-Div. AGIP, the percentage amount of maintenance action can be divided as follows (Sebastianelli and Bosco, 1999):

1. 66% “scheduled” maintenance,
2. 34% “emergency” maintenance, whose 6% is due to gas turbine block.

The aim of the “on condition” maintenance is to reduce the “emergency” maintenance (2) as much as possible and to optimize the “scheduled” maintenance (1), which is based on the manufacturer experience in terms of components life and performance degradation versus working hours. The “on condition” maintenance may replace the scheduled maintenance actions, which do not take into account the actual gas turbine health state, for "ad hoc" actions, which instead descend from the real operating state of the machine. Therefore, the “on condition” maintenance requires the up-to-date knowledge of the actual values of the parameters which are indices of the gas turbine component (compressor, turbines, combustion chamber) health, as, for example, efficiencies, characteristic flow passage areas and pressure drops along the gas path. This allows to plan in advance maintenance stops in respect of the actual gas turbine health state, of the availability of stand-by machines and of the production requirements. Furthermore, if the actual characteristic parameters are known, it is possible to adapt the gas turbine control logic to its actual health state, so that it might be possible to recover up to 50% of the efficiency loss due to aging and deterioration.

This paper describes a methodology for the analysis of the gas turbine health state based on "Gas Path Analysis", and the techniques for the improvement of the diagnostic tool reliability. The firsts results of the application of the methodology for the operating state determination of gas turbines operating in the natural gas compression plant of ENI – Div. AGIP in Casalborsetti (RA - Italy) are presented.

EARLY DETECTION OF DAMAGE IN HEAVY DUTY COMBUSTION TURBINE BLADES FOR ELECTRIC GENERATION

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Abstract

The paper treats some problems occured during the operation of modern heavy duty combustion turbines for energy generation belonging to ENEL fleet. The content describes the specific base problems encountered and the most suitable detecting technologies set up in order to have early detection of damage to limit the replacing expenses and to save additional repairing costs.

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The Development of Analytical Techniques for Application in Condition Health Monitoring

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Abstract:

With increasingly tight financial constraints being placed on equipment operators, there is a continual need to both increase reliability and reduce the cost of ownership. To meet these requirements, maintenance managers must be in a position to make timely decisions about the serviceability of equipment that maximise availability for a given cycle cost.

Condition Health Monitoring (CHM) is the term given to a collection of methods that convey information about the mechanical condition of a system. Specifically CHM seeks to reduce maintenance and therefore cost, and to increase unit life, availability and operational safety.

It is important to appreciate that no single CHM technique can be relied upon to predict all possible failure modes and the decision as to which method or suite of methods to use depends heavily on the equipment being monitored. Whichever method is employed, it must provide confidence in the timely warning of impending malfunction, whilst minimizing the occurrence of unwarranted alerts.

CHM techniques can be divided into two main categories: Off-line, which involves sampling and subsequent analysis, and On-line, which monitor specific parameters of a system in "real time".

The Mechanical Sciences & Structures (MSS) group of the Defence Evaluation & Research Agency (DERA) is currently involved in the development of a number of both on and off-line techniques for military and civilian customers. The aim of this paper is to examine these methods and to discuss the intended applications within CHM.